ESPC Coupled Global Ensemble Design

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LONG-TERM GOALS

The long-term goal of the project is the development of a coupled atmosphere-ocean ensemble prediction system that can provide probabilistic environmental information to meet Navy and DoD operations and planning needs throughout the globe from undersea to upper atmosphere and from the Tropics to the Poles on the weekly to monthly timescale.

OBJECTIVES

The objective of this project, which is the ensemble component of the ESPC effort, is the development of a coupled atmosphere ocean ensemble prediction system that will provide coupled atmosphere-ocean probabilistic predictions out to 30 days. The separate component ensemble systems will be developed first, followed by the development of the coupled system infrastructure and forecasting capabilities. Initial operational capability is targeted for 2018.

APPROACH

1. It is recognized that for long term predictions (30 days) that are beyond the predictability limit of many processes, the most important information that can be provided will be the probability distribution function (PDF) of environmental conditions. It is expected that this distribution will have skill. To accomplish this, it will be necessary to combine the existing independent ensemble prediction capabilities for the atmosphere, ocean, and waves as well as implement new ensemble capabilities for ice and land systems. It would be expected that the Ensemble Transform method as implemented in each system would be the initial capability for ensemble forecasts. Extensions to fully coupled ensembles would be the next step.
2. Develop an extended-range global atmospheric ensemble forecasting system using the Navy Global Environmental Model (NAVGEM). Couple NAVGEM to a simple SST model that captures the diurnal cycle. This simple SST model may eventually be combined with HYCOM (the models can be complementary to each other).
3. Develop and implement a “persistent SST anomaly technique in which the initial SST anomaly is superimposed upon an SST annual cycle through the forecast integration.
4. Develop and implement the capability to produce initial SST perturbations created from NCODA estimates of analysis error variance.

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5. Development and implement a new capability to support global ocean ensemble cycling, including a) implementation of a cycled reduced-resolution ocean ensemble centered on the full resolution analysis and b) update/improve the existing ocean ensemble transform code to better represent local features in the analysis uncertainty.
6. Modify the ocean ensemble transform code as needed to work with HYCOM.
7. Address the generation of analysis perturbations for ice cover and the initialization of ice for the ocean-only and coupled ensemble.
8. Expand existing ensemble post-processing and product generation to handle the volume of output generated from high-resolution HYCOM ensemble and extract appropriate probabilistic forecast output.
9. After the development of these individual components, a coupled ensemble prediction infrastructure will be developed. Initial perturbations for the coupled system may be provided from the development of the coupled data assimilation system (under a separate project).

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WORK COMPLETED FOR FY14

Atmosphere component:

1) Milestone: Develop ensemble system with simple diurnal SST model

 › Synopsis:

 A simple model of diurnal SST variation was incorporated into the NAVGEM code and tested. Earlier efforts with the preceding generation of the global atmospheric prediction system, NOGAPS (Navy Operational Global Atmospheric Prediction System), had shown that implementation of the simple model improved a number of probabilistic measures of forecast-ensemble performance. The formulation of the SST model implemented in NAVGEM is identical to that used in NOGAPS; It represents diurnal SST variation in a 3m-thick sub-skin layer as a function of shortwave and longwave radiative flux, evaporation, molecular thermal conduction, and wind-driven turbulent diffusion; The model omits skin-layer cooling effects.

 › Experimental Details:

 The implementation of the diurnal SST model within NAVGEM was tested using an ensemble experiment for the month of July 2013. This test period was selected because it spans the time frame when the Northern Hemisphere (NH) oceans are subject to the greatest diurnal heating. In the experiment, a 20-member NAVGEM v1.2 forecast ensemble was generated twice daily at operational resolution (T239 spectral resolution and 50 vertical levels), with the diurnal SST model turned on. The forecasts for each ensemble initialization were integrated to the 336h lead time, to ensure adequate time for the SST diurnal cycle to interact with the atmosphere. Initial conditions for the ensemble were generated using the operational ensemble transform (ET) analysis perturbation scheme. For comparison, a control ensemble was run for the same period, with a configuration identical to that of the test ensemble except that the diurnal SST model was turned

off. An ensemble scorecard was completed for both the test forecast ensemble and the control ensemble. The scorecard mimicked the official FNMOC operational ensemble scorecard and measured performance using four metrics: Root-mean-square error of the ensemble mean (RMSE), Continuous Ranked Probability Skill score (CRPS), the bias of the ensemble mean, and a measure of the spread-skill relationship. The scorecard focused on 10m wind speed and 2m air temperature, as these are the primary atmospheric variables of interest at the air-ocean interface.

Ocean component:

1) Milestone: Develop and implement a new capability to support global ocean ensemble cycling.

› Synopsis

Code to refine and reduce ocean model fields between high and low resolution model configurations has been implemented and applied in the ocean 4DVar NCOM/NCODA system. The code has been tested with regional NCOM configurations. We have just begun the task of parallelization of the Ensemble Transform code, evaluating on the MPI domain decomposition code in NCOM and the volume duplication in NCODAv2. We are maintaining a daily cycling regional ocean ensemble based on the Ensemble Transform with weekly 60d forecasts.

› Experimental Details

The extended taus of the long ocean ensemble forecast are forced by taking eight years of NOGAPS output and performing space-time deformation of the historical 3h forcing. Lateral boundary conditions use a multi-year history of global ocean model output.

RESULTS

Atmosphere component:

1) Milestone: Develop ensemble system with simple diurnal SST model

Inclusion of the diurnal SST model in the NAVGEM ensemble yielded aggregate modest but positive (i.e. improved) scores relative to the control ensemble. These modest positive scores are in line with expectations based upon the earlier efforts with the NOGAPS ensemble. When the scores are broken down by variable the findings are mixed, with the SST model leading to aggregate improvement for 10m wind speed but aggregate degradation for 2m air temperature. Considering 10m wind speed, the SST model generally leads to widespread small but statistically significant improvements, mainly in the ensemble 10m wind speed RMSE and CRPS metrics. An example of these improvements is shown for the case of the tropical Atlantic Ocean region in Fig. 1.

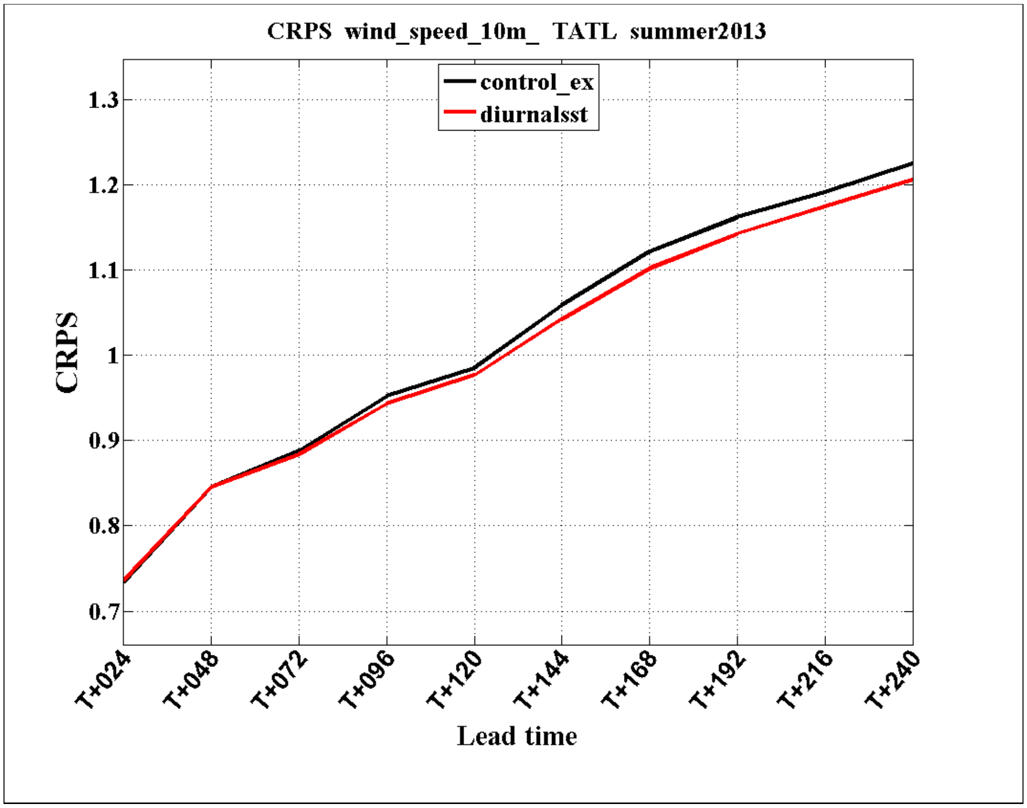

Figure 1 (above). Average CRPS of ensemble-mean 10m wind speed for the tropical Atlantic Ocean region. Black (red) line indicates the values for the control ensemble (test ensemble with diurnal SST variation).

Considering 2m air temperature, the SST model induces small but statistically significant improvements to ensemble 2m air temperature RMSE and CRPS in the NH Extratropics. This is illustrated in Fig. 2 for the North Pacific Ocean region.

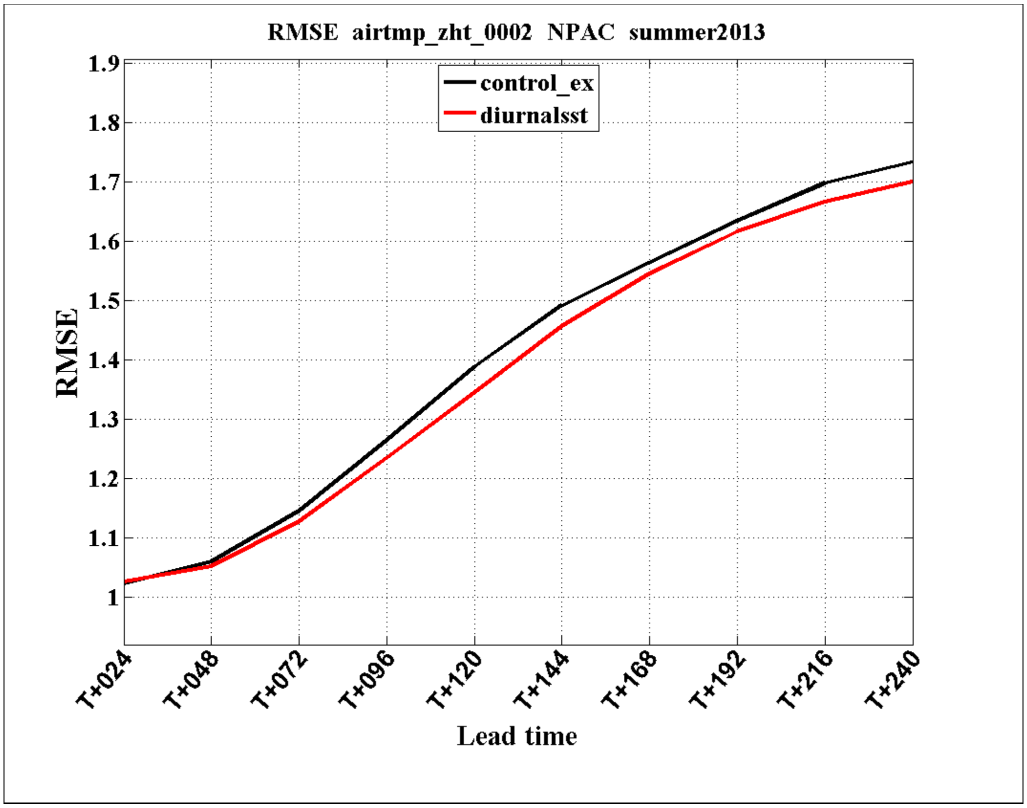

Figure 2 (above). Average RMSE of ensemble-mean 2m air temperature for the North Pacific Ocean region. Black (red) line indicates the values for the control ensemble (test ensemble with diurnal SST variation).

On the other hand, the SST model has some substantial negative effects on the 2m air temperature bias in the Tropics and on the 2m air temperature spread-skill relationship in the NH Extratropics. The negative effect on tropical bias owes partially to the fact that the SST model as implemented does not provide for cooling below a base temperature that is defined by the SST analysis valid at the initialization time. This means that the model (through the process of diurnal heating) can only exacerbate NAVGEM's existing warm bias in tropical 2m air temperature. The warm bias is further exacerbated owing to NAVGEM's existing negative bias in 10m wind speed, which leads to ocean mixing that is too weak and by extension to diurnal heating that is too strong. The overly large values of diurnal heating not only affect the air temperature bias but also produce too much air temperature variance, negatively impacting the air temperature CRPS and spread-skill metrics.

Several options to mitigate the negative effects on air temperature bias and spread-skill have been identified. One is to include a representation of the skin layer in the SST model, to take advantage of this layer's known 0.1-0.3 °C cooling influence. Another is to apply a cap to the amount of diurnal SST change that the SST model can impart. A third option is to incorporate a latitudinal or regional mask in the SST model, with the objective to eliminate excessive diurnal changes in the higher latitudes. Mitigation options will be tested in early 2015.

Ocean component:

1) Milestone: Develop and implement a new capability to support global ocean ensemble cycling.

Completed a substantial amount of code and script development to form the software foundation for a global ocean ensemble. Began collecting an archive of long ocean ensembles.

IMPACT/APPLICATIONS

These experiments allow for an assessment of potential extended range probabilistic forecast utility (both in the atmosphere and in the ocean) for Navy-relevant metrics such as potential for high winds, extreme events, or tropical cyclones (ocean examples?). Development of a skillful coupled ensemble forecast system will allow for DoD decision support on monthly time scales as well as improve capabilities reliant upon extended-range forecasts such as trans-ocean ship routing.

TRANSITIONS

The potential for extended-range forecasting demonstrated in this program will be transitioned to operations through existing and future 6.4 programs.

RELATED PROJECTS

Success of this project is dependent upon the success of the other ESPC components, particular the development of the coupled global prediction system (WU-1 ESPC), and the development of coupled data assimilation, which would provide consistent coupled initial perturbations for the ensemble system. Development of atmospheric component of the coupled ensemble system will leverage work ongoing under the RTP Project (get correct name of ship routing ensemble project) and under the 6.2 base-funded project “The Madden Julian Oscillation-Key to Coupled Extended-range Prediction”.